

# Development of a Multi-Band Shared Aperture Reflectarray/Reflector Antenna Design for NASA

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**Abstract**— A dual-band (Ka/W) shared-aperture antenna system design has been developed as a proposed solution to meet the needs of NASA’s planned Aerosol, Clouds, and Ecosystem (ACE) mission. The design is comprised of a compact Cassegrain reflector/reflectarray with a fixed W-band feed and a cross track scanned Ka-band Active Electronically Scanned Array (AESA). Critical Sub-scale prototype testing and flight tests have validated some of the key aspects of this innovative antenna design, including the low loss reflector/reflectarray surface.

More recently the science community has expressed interest in a mission that offers the ability to measure precipitation (Ku-band with scanning) in addition to clouds and aerosols. In this paper we present findings from a design study that explores options for realizing a tri-frequency (Ku/Ka/W), shared-aperture antenna system to meet these science objectives. Design considerations included meeting performance requirements while striving to minimize payload size, weight, prime power, and cost. The extensive trades and lessons learned from the ACE system development were utilized as the foundation for this work.

**Keywords**— Reflectarrays, Reflectors, Phased Arrays, Millimeter Wave, NASA Earth Science

## I. BACKGROUND

A high efficiency, dual-band (Ka/W), shared-aperture antenna system design has been developed for NASA’s planned Aerosol, Climate, and Ecosystem (ACE) mission [1] – [4]. The architecture provides a fixed nadir beam at W-band and a cross-track scanning beam at Ka-band using the same primary parabolic cylinder reflector. The enabler for this design is the low loss reflectarray surface on the primary reflector. For Ka-band operations the antenna is fed by an Active Electronically Scanned Array (AESA) line feed at the virtual focal line of the primary reflector (Cassegrain optics). The line feed provides polarimetric information via dual-linear polarized receive beams. For W-band operations a dual-pol beam waveguide system is located at the virtual focal point of the reflector. The reflectarray surface focuses the W-band energy in azimuth and elevation to/from the main reflector. It also enables the two bands to have co-aligned beams with separate feeds and sub-reflectors.

A sub-scale antenna was fabricated, tested, and flown to demonstrate the viability of the ACE mission antenna system. The sub-scale antenna, shown in Figure 1, is an offset-fed

parabolic cylinder with an aperture size of approximately 2’ x 2’ and the same f/D as the full scale ACE design (Figure 1). At Ka-band it is fed by a fixed beam line array of dual-pol patch antennas at the focal line of the reflector. AESA beam steering is replicated by swapping among a set of scanned, fixed beam line feeds during range testing. For W-band operations a dual-pol horn is located at the virtual focal point of the reflector and a reflectarray surface focuses its energy in azimuth and elevation. The performance of the sub-scale antenna was successfully measured in a compact antenna range at GSFC in Greenbelt, MD. Measured to modeled agreement was excellent. The sub-scale antenna was ultimately installed on the NASA ER-2 aircraft and used for high altitude, sub-orbital radar measurements at W-band.

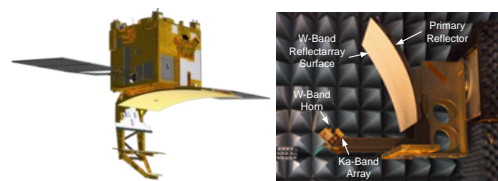


Fig.1. (Left) Model of the dual-band, shared-aperture antenna architecture for the ACE mission and (right) the sub-scale

## II. DRIVING REQUIREMENTS

The antenna concepts presented in this paper are supporting a tri-band radar aimed at measuring reflectivity, Doppler, and polarimetric data of clouds and precipitation in the earth’s atmosphere [3] – [4]. Retrieval products include data such as particle size, rain rate, and weather system dynamics. The primary performance metric for the radar system is sensitivity. From an antenna design standpoint the principal performance metrics impacting sensitivity are radiated power, gain, and the two-way side lobe level. Striking a balance between size, weight, power, cost, and complexity are also factored into the overall system design.

From a capability standpoint the architectures considered can be grouped into two main categories: Category 1 includes those providing Ku/Ka-band scanning and a W-band fixed nadir beam, and Category 2 includes those providing tri-frequency scanning capability. An additional subgroup is comprised of architectures providing dual-band scanning at Ka- and W-band.

### III. ANTENNA SYSTEM DESIGN

Numerous antenna architectures were identified and explored to establish leading candidate architectures within Categories 1 and 2. Primary emphasis was placed on the overall aperture design (type of optics, f/D, feed design & placement, etc.) as well as the AESA transmit/receive (T/R) modules (device technology, power requirements, packaging, etc.).

#### A. Antenna Aperture Design

The ACE antenna architecture was the starting point when considering options for adding Ku- and/or W- band scanning. Determining how to best incorporate these AESAs into a shared-aperture design was the main objective. The design trade space included a number of options such as using single- or dual-band AESA line feeds, feed placement possibilities, and utilizing shared sub-reflectors.

In nearly every tri-band architecture identified, one or more AESA line feeds must be displaced from the focal line of the parabolic cylindrical reflector; the displacement aberrations cause a gain reduction, sidelobe degradation, and beam misalignment. The low loss reflectarray surface and synthesis tools developed for the ACE antenna design [1] – [3] were the foundation for correcting for these aberrations and in opening the design space for feed placement. This technology enables two or more AESA line feeds to share the same reflector and subreflector with high efficiency, no pattern distortion, and co-aligned beams.

Within Category 1 there are various architecture trades for achieving the Ku/Ka-band scanning and a W-band nadir beam. Trades include design details such as accepting degraded performance of a feed displaced from the focal line versus correcting for this via a reflectarray/reflector on a subreflector. Individual band versus dual-band AESA line feeds were considered; performance, complexity, flexibility, and prime power are some of the important factors. Ultimately two primary candidates were selected within Category 1

Similarly, for Category 2 a number of candidate architectures were identified and assessed to provide a shared-aperture, tri-band scanning antenna. For Category 2 the W-band beam waveguide and its associated subreflector is replaced by an AESA line feed. Complexity and mechanical implementation point towards sharing the same parabolic subreflector among the three AESA feeds. Many of trades within this category are similar to those of Category 1. Complexity, cost, prime power, and technology maturity are especially important considerations for this category.

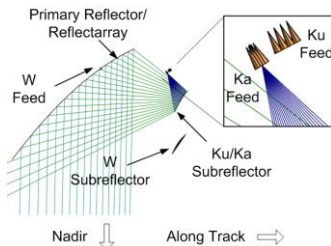


Fig.2. View of an RF model used on the assessment of one of the primary candidates of Category 1.

#### B. AESA T/R Module Design

The AESA T/R modules are a critical component of the tri-band radar system. NGMS and GSFC are currently developing a Ka-band T/R module that is targeting the design requirements of the ACE mission; this work is funded by NASA's Earth Science and Technology Office through the Instrument Incubator Program. The scope of this work includes designing, building, and testing a Ka-band module. The lessons learned from the design of this module, as well as the extensive experience of NGMS in the area of production AESAs, were leveraged to develop concepts and identify design trades for Ku and W-band modules.

Primary trades for the T/R modules included the device technology, the RF front-end architecture, and its layout and packaging. Conceptual layouts were created for the Ku- and W-band modules. These were used to explore the form, fit, and function of key components (HPA & LNA) and to examine the space required for adjacent line feeds.

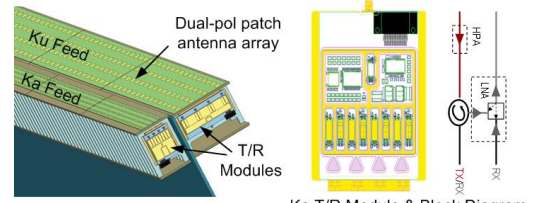


Fig.3. (Left) Modeled view of adjacent Ka and Ku AESA line feeds and (right) detailed layout of the Ka module and its block diagram.

#### ACKNOWLEDGMENT

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